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INSIDE

Distributed, Active Extension in Bransfield Basin, Antarctic Peninsula: Evidence from Multibeam Bathymetry

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ABSTRACT

Bransfield basin, a marginal basin off the west coast of the northern Antarctic Peninsula, lies in a unique tectonic environment with a basement of Paleozoic to Mesozoic accretionary wedge material. Although active subduction occurred during most of the past 200 m.y., it stopped or slowed dramatically at about 4 Ma when the Phoenix-Antarctic spreading center was abandoned offshore, leaving a small remnant of the former Phoenix plate incorporated in the Antarctic plate. Even though geochemical data indicate that unaltered basalt dredged from Bransfield basin is like midocean ridge basalt, there is no clear evidence for normal seafloor spreading. In November 1995, *RVIB N.B. Palmer* spent three weeks mapping the seafloor in Bransfield basin and searching for hydrothermal activity. The multibeam bathymetric chart of the Central Bransfield basin shows submarine volcanoes and striking, lineated seafloor features that dredging indicated were vesicular basalt. The chemistry of the rocks, combined with high heat flow and evidence for active hydrothermal circulation, strongly suggests present-day extension. At least four parallel zones of linear extrusions can be seen in the multibeam data. Whereas the bathymetry provides new insight into the mode of extension in the basin, it does not explain why or how extension is occurring. The evidence strongly supports active extension in accretionary wedge–derived continental crust that produces linear cracks that leak magma. The present extensional regime may lead to seafloor spreading, but the thickness of the crust in Bransfield basin suggests that normal seafloor spreading is yet to occur and any attempt to correlate magnetic anomalies is premature.

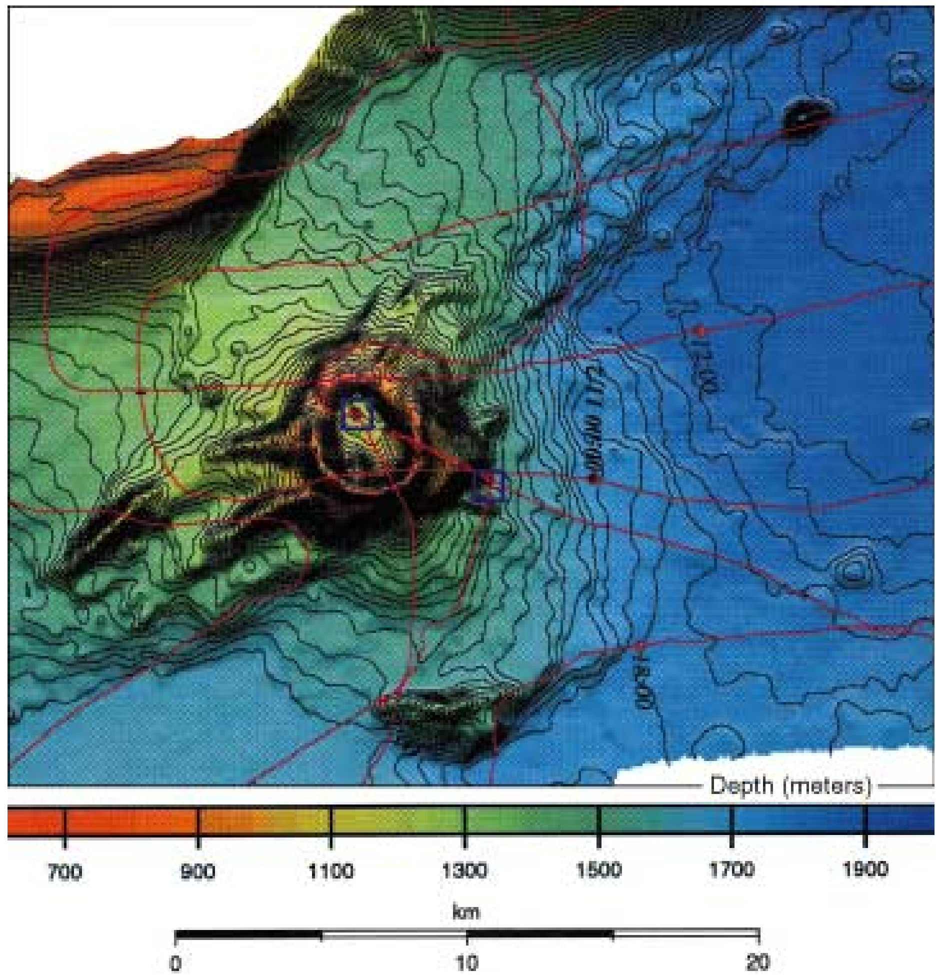

Figure 1. Detail of a Seabeam 2112 multibeam bathymetric chart of Bransfield basin (Antarctic Peninsula) showing Volcano Orca (González-Ferrán, 1991). The shallow shelf of the South Shetland Islands is to the upper left. The contour interval is 25 m; depths, in meters, are indicated in the color bar. Deepest values are just greater than 1900 m; shallowest are slightly less than 600 m. The red lines show the ship-track; the one station indicated in the center of the caldera is where the Oregon State University instrument sled was lowered but no evidence of hydrothermal venting was found. Three dredges (see Plate 1, center spread in this issue, for locations) recovered vesicular glassy basalts from this feature (Keller, 1996). Note the northeast-southwest–trending bathymetric steps that intersect the volcano. Radial dikes appear to extend from the volcano and curve into approximate alignment normal to the regional extensional field, particularly immediately to the west of the volcano. In the upper right-hand corner, there appears to be a small volcanic feature about 100 m high that is directly on line with the northeast-southwest trend of the bathymetric steps. The 200-m-high feature at the bottom of the figure is at a distinct angle to the overall northeast-southwest trend.

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INTRODUCTION

The origin of Bransfield basin has intrigued researchers for many decades (summarized in Barker and Dalziel [1983] and Lawver et al. [1995]), because the more we learn about its structure and morphology, the more difficult it is to postulate a simple model to explain its tectonic evolution. Subduction has occurred along the southern South America–Antarctic Peninsula margin for most of the past 200 m.y. (Tanner et al., 1982, Barker and Dalziel, 1983; Pankhurst, 1983), which has led some to surmise that Bransfield basin formed as a back-arc basin. Young basalts erupted in Bransfield basin have compositions similar to basalts from back-arc basins in the western Pacific (Keller et al., 1996), so this might not be an unreasonable assumption. In contrast, though, geophysical data (Guterch et al., 1992; Grad et al., 1993) indicate that the crust beneath Bransfield basin is far thicker than that produced by seafloor spreading.

Bransfield basin does not overlie a typical continental cratonic margin; the northern Antarctic Peninsula basement seems to consist of a Paleozoic to Mesozoic accretionary wedge (Dalziel, 1984) that was originally the outboard margin of southern South America during the early Mesozoic. Complicating a simple subducted-slab–back-arc basin story is the fact that the last sections of the Phoenix-Antarctic spreading center ceased spreading at about 4 Ma and now lie abandoned to the northwest of Bransfield basin (see inset, Plate 1, center spread, p. 16–17) (Barker, 1982). The last remnant of the Phoenix plate was incorporated into the Antarctic plate at that time, and subduction at the South Shetland Trench (Plate 1) slowed dramatically but is apparently still active (Barker and Austin, 1994). Exactly how and why active extension now occurs in this unique setting remains a mystery (Lawver et al., 1995). Multibeam bathymetric data (Plate 1 and Gracia et al., 1996) give us visual clues to the mode of active extension, if not the reason for extension.

TECTONIC SETTING: NOT A "NORMAL" BACK-ARC BASIN

The magmatic record of the northern Antarctic Peninsula (Graham Land) suggests that subduction of Pacific oceanic crust extended back to at least 200 Ma (Pankhurst, 1983). During the Early Jurassic and possibly throughout the Triassic, the Antarctic Peninsula was located outboard of the southern end of South America (Grunow et al., 1992). Only in the Late Jurassic did the peninsula rotate away from southern South America (Lawver et al., 1992; Cunningham et al., 1995). In the vicinity of Bransfield basin, there is no direct evidence of any Precambrian basement below the Paleozoic to Mesozoic accretionary prism (Dalziel, 1984). To the southwest, some crystalline basement does crop out (Storey and Garrett, 1985), but that is south of 70°S and sufficiently far from Bransfield basin to not be pertinent (Barker et al., 1991). Dalziel (1984) categorized northern Peninsula basement rock as either products of subduction-related accretion (for the metamorphic rocks), or sedimentation in a fore-arc environment along the Pacific margin. Lithology of the regional basement rocks indicates that the metamorphic rocks represent pelagic and volcanic material from the ocean floor tectonically interleaved with slices of oceanic lithosphere. The sedimentary strata, consisting of graywacke and shale of turbidite facies associated with rare mafic pillow lava, were deposited partly in trench-slope basins within the zone of active deformation in the accretionary wedge.

Island-arc volcanism along the South Shetland Islands may have been episodic, with maxima at 130–110 Ma, 90–70 Ma, 60–40 Ma, and finally at 30–20 Ma (Pankhurst and Smellie, 1983; Birkenmajer et al., 1986). There is no arc-related magmatism in the South Shetland Islands much younger than 20 Ma, which Barker

(1982) ascribed as a consequence of the subduction of young oceanic crust. We know from major plate motions (Lawver et al., 1995) that subduction must have continued at the South Shetland Trench from 20 Ma to at least 4 Ma, even though there was no apparent island-arc volcanism during that period. The Phoenix-Antarctic spreading center collided with the subduction zone along the Peninsula to the southwest of Bransfield basin (Plate 1), the last section having been subducted at about 4 Ma (Barker, 1982). Recently active, non–island-arc volcanism is evident in Bransfield basin (Smellie, 1990), both Deception Island (recent eruptions in 1967, 1969, and 1970) and Bridgeman Island (numerous reports of fumarolic activity between 1821 and 1880) being the two main volcanic features (Plate 1).

Seismic reflection data in Bransfield basin have been reported by several different groups as summarized by Barker (1976), Gamboa and Maldonado (1990), the GRAPE team (1990), Larter and Barker (1991), Acosta et al. (1992), and Barker and Austin (1994). The seismic reflection work, as well as continuing active seismicity (Pelayo and Wiens, 1989) confirm that Bransfield basin is undergoing extension. Barker and Austin (1994) addressed the question of the mode of extension by showing multichannel seismic reflection results that document active northwest-southeast extension along several axes. They suggested that some of the normal faults they see in the seismic reflection data are the result of linear subbottom intrusions.

Magnetic anomaly profiles across Bransfield basin produce a strong positive magnetic anomaly over the linear extrusive features. The first paper to discuss magnetics in the Bransfield basin (Roach, 1972) correlated the major positive anomaly with the Central Anomaly (0.7 Ma to present), and suggested that seafloor spreading took place over the past 1.4 Ma. González-Ferrán (1991) concluded, on the basis of aeromagnetic data from Bransfield basin, that rifting produced 5 to 15 km of extension during the past 2 m.y. and gave a total spreading rate of 2.5–7.5 mm/yr. Gracia et al. (1996) gave a maximum age of seafloor spreading of 0.7 Ma and a rate of 0.83 mm/yr total spreading rate.

Heat-flow profiles taken on two earlier cruises (Nagihara and Lawver, 1989; Lawver et al., 1995) yielded 63 measurements, of which 16 were greater than 220 mW/m^2 and one was 626 mW/m^2. Such high heat-flow values combined with large variability suggest that active hydrothermal circulation is present in Bransfield basin. On a *Palmer* cruise in March 1993, eight dredge hauls were made on bathymetric highs in Bransfield basin, including the northern end of Edifice D (Gracia et al., 1996), which we call the Three Sisters (Plate 1) (named after the Three Sisters volcanoes in the Cascade Range of Oregon). Keller et al. (1996) found that dredge D1 from the northeastern end of the Three Sisters recovered fresh, glassy vesicular basalt with a chemistry similar to that of the Lau Basin, a "standard" Pacific backarc basin (Hawkins, 1995). Both D1 and the three dredges (D2–D4) from the submarine volcano shown in Figure 1 (Orca Volcano of González-Ferrán, 1991), have low $^{87}Sr/^{86}Sr$ and high $^{143}Nd/^{144}Nd$ ratios, similar to depleted upper mantle values of mid-ocean ridge basalt (Keller et al., 1996). These same samples have some of the highest $^{206}Pb/^{204}Pb$ values found in the Bransfield basin but are still within the range of mid-ocean ridge basalt (MORB). The unaltered basalts show a 0.5% to 2% mixing of subducted sediment with a depleted mantle source, but it is not known whether the sediment component is from the recently subducted Phoenix crust or is contributed by the accretionary wedge basement of Bransfield basin.

DATA COLLECTION

In November 1995, *RVIB N.B. Palmer* spent three weeks in the vicinity of Bransfield basin using the Seabeam 2112 multibeam system to map the seafloor and the Oregon State University (OSU) instrument package to look for evidence of hydrothermal venting. The OSU package included a direct-wired CTD (conductivity-temperature-depth) transmissometer, nephelometer, turbidity meter, backscatter sensor, flow-through chemical sensor, 12-bottle rosette, altimeter, and an attitude module to determine tilt, pitch, and heading of the package (Klinkhammer et al., 1995). The high but variable heat-flow data (Nagihara and Lawver, 1989; Lawver et al., 1995) made us confident that we would locate active hydrothermal vents in the central Bransfield basin. Initially, sea-ice conditions dictated that the hydrothermal vent search should concentrate on the bathymetric highs that protrude above the reasonably flat-lying sediments and not at the site of highest heat flow. Bathymetric surveying occupied 10 to 12 hours per day and station work the remainder. For base maps, we used the GPS-controlled bathymetric map of Klepeis and Lawver (1994, 1996), which was a mixture of multibeam Hydrosweep coverage from *R/V Ewing 91-01* and single-beam coverage from *R/V Polar Duke* cruises. We also had a preliminary copy, thanks to Miquel Canals, University of Barcelona, of the Simrad multibeam bathymetric map produced during the GEBRA 93 cruise (Gracia et al., 1996).

The ice-clogged waters of Bransfield basin not only limited our exploration capability, but also made systematic surveying difficult. Stopping for stations and returning to sites of interest as well as avoiding sea ice resulted in an erratic ship track and a "patchwork quilt" of data acquisition, with some redundancy. At the redundant localities there was excellent bathymetric agreement, particularly when water-temperature profiles were used to calculate accurate sound velocities. Water-temperature profiles were taken from expendable bathythermographs (XBTs) and from frequent CTD casts. The CTD data were far superior to the XBT data; water temperature at depths between 100 and 400 m resulted in velocity differences of up to 10 m per second. While normal-incidence bathymetric data will give good relative depth results using standard water-velocity corrections, bathymetric data collected at low angles of incidence are highly dependent on temperature variations in this stratified water column. The multibeam bathymetry was recalculated using appropriate velocity models, and the final map (Plate 1) was made using the GMT (Wessel and Smith, 1995) gridding and plotting program. Small gaps in the data were interpolated to produce a nearly seamless map. The gridding program did produce extrapolated data along the edge of the mapped region that extends up to 1 km beyond the real data. These artificial data are most apparent as the "sidewalk" along the South Shetland Islands edge of the mapped region (Plate 1). Once the grid file for the region was created, it was subsampled to produce smaller scale maps that were used to navigate the OSU instrument sled within regions of suspected hydrothermal vent sites.

MULTIBEAM BATHYMETRY OF THE CENTRAL BRANSFIELD BASIN

We concentrated our survey along the South Shetland Islands side of the basin (Plate 1) because most of the significant bathymetric features are there. The tectonic map of the Scotia Arc (British Antarctic Survey, 1985) suggested that the abrupt bathymetry of the South Shetland Island side of the Bransfield basin is a normal fault, and we found slopes as steep as 22° immediately north of the submarine volcano, Orca Volcano (Fig. 1). The steepest slope (>31°) was on the south wall of the submarine volcano, Orca Volcano, rising almost 600 m in <1 km. The southeastern slope of the Bransfield basin toward the Antarctic Peninsula is at most a few degrees, except in the vicinity of the scarp at 62°18'S, 57°45'W (Plate 1) which is controlled by a subsurface intrusion (Barker and Austin, 1995).

The shipboard gravity data (Ghidella and Holik, 1995) are shown in the upper-left corner of Plate 1. Free air gravity values for Bransfield basin are relatively uniform and correlate with water depth, with the exception of the major volcanic features. Bridgeman Island (62°S) divides the Central Bransfield basin from the deeper

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Bathymetry *continued from p. 3*

Eastern Bransfield basin. Deception Island (63°S) produces a gravity high that also spans the width of the Bransfield basin, although its amplitude is smaller than that of Bridgeman Island. Orca Volcano does not have a basin-spanning gravity anomaly, but it has a high amplitude locally because some of the lowest gravity values are found immediately to the southwest of Orca Volcano. Although not as prominent as either the Bridgeman or Deception Island anomalies, the gravity anomaly of the Three Sisters structure extends parallel to the basin-spanning anomalies of the two islands. Edifice A of Gracia et al. (1996) produces a large gravity anomaly in its immediate vicinity comparable to that of Orca Volcano. Although larger than that of the Three Sisters, this anomaly does not span the basin and is oriented more nearly east-west than the other three northwest-southeast basin-spanning anomalies. The zone of subsurface extension recognized by Barker and Austin (1994) at 57°30'W is apparent on the shipboard gravity as well as on satellite gravity data (Sandwell and Smith, 1992). There is a gap in the gravity signature between Edifice F (Gracia et al., 1996) and Bridgeman Island. No gravitational evidence was found for the bathymetric levels suggested by Gracia et al. (1996), and the parallel morphologic steps suggested by them are not seen in our bathymetric data. The changes in depth from shallower near Deception to deeper near Bridgeman Island possibly result from regional doming (uplift) in association with the largest submarine edifices, particularly Edifice A and the Three Sisters. The doming produces cross-basin dams that trap the principally volcanic-ash–derived sediment produced during eruptions of Deception Island.

Edifice A is a particularly interesting seafloor structure at 62°52'S, 59°52'W (Plate 1). Gracia et al. (1996) suggested that it was originally a circular submarine volcano subsequently split apart by a linear extrusion that extends from 59°36'W to 60°05'W parallel to the basin's long axis. In fact, the "split" structure is really circular (a 5.2-km-diameter circle can be laid on the remnants of the crater wall), and the entire volcano is about 16 km in diameter at its base. It is more likely that the linear ridge (extrusion) predates or was coincident with formation of the conical volcano.

Orca Volcano (Fig. 1) is also a nearly circular submarine volcano. It may have erupted with radial dikes preferentially aligned with the regional northwest-southeast extensional field (Barker and Austin, 1994). Although a straight line on the mercator projection of Plate 1 connects the center of the Deception Island caldera with Orca Volcano and with Bridgeman Island, this alignment does not necessarily imply that these eruptive centers identify the zone of most recent extension. That zone instead seems to lie even farther to the southeast (Barker and Austin, 1994) and may in fact lie to the southeast of the zone of active hydrothermal venting indicated by temperature and suspended-particle anomalies, that were found along the central axis of the Three Sisters, at the southwest extension of the Three Sisters, and at Edifice F (Klinkhammer et al., 1995). A line between those two structures overlies the area of highest heat flow found at 62°18.5'S, 57°42'W (Lawver et al., 1995). This leads us to suggest that magma at depth is preferentially directed to Deception Island and Bridgeman Island. On the basis of gravity data, these islands, and to a lesser extent Orca Volcano, have deep roots. It appears that the most active zone of extension and magmatic activity has shifted to the southeast and is aligned with the Three Sisters, Edifice F, and the zone of highest heat flow. Subsurface extension seen in the multichannel seismic reflection data (Barker and Austin, 1994), the scarp at 62°18'S, 57°45'W (upper left inset of Plate 1) and various small features to the east of Edifice F may mark the zone of the next linear extrusion.

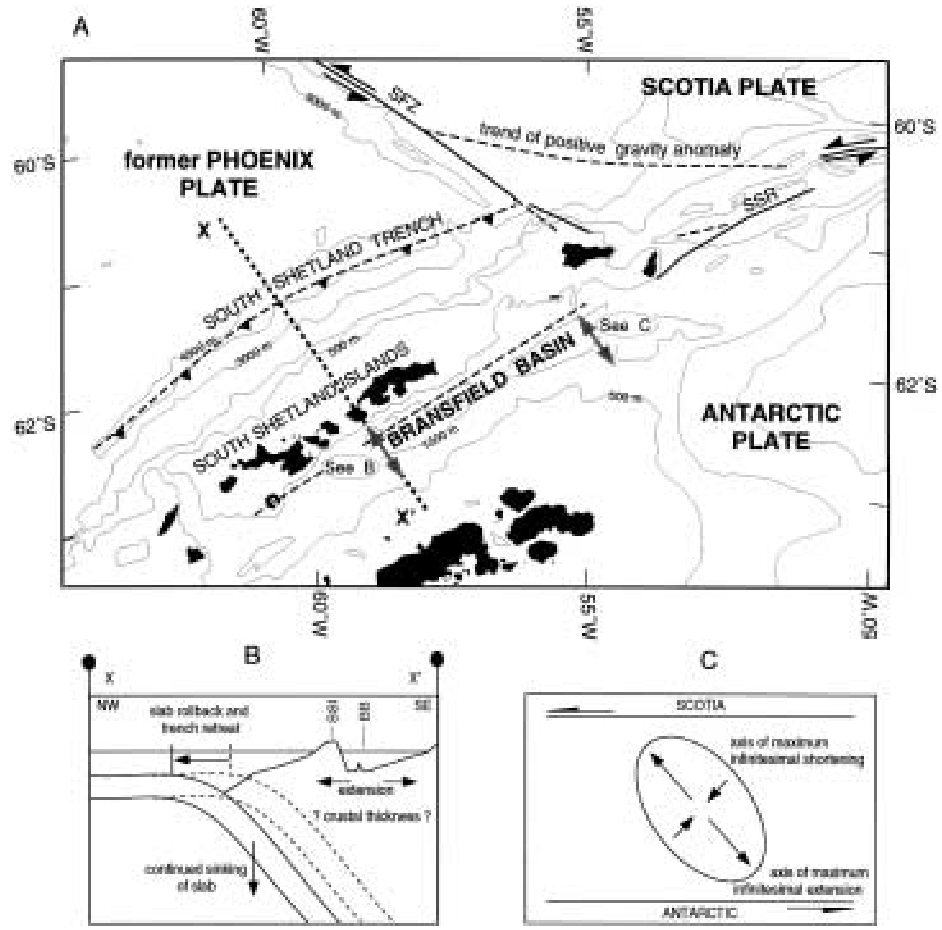

Figure 2. A: The regional extension field in Bransfield basin. B: A cross-sectional view of the continued sinking of the "frozen in place" slab that may produce horizontal extension in Bransfield basin. Extension in the Eastern Bransfield basin may result from major plate interaction between the Scotia and Antarctic plates that are now in the process of reorganizing in the wake of the demise of the Phoenix-Antarctic spreading center (Klepeis and Lawver, 1996). C: The stress field (plan view). SFZ = Shackeleton Fracture Zone; SSR = South Scotia Ridge. This figure is adapted from Klepeis (1993).

EVIDENCE FOR EXTENSION WITHOUT SEAFLOOR SPREADING

What we see recorded in the multibeam bathymetric data may be tectonic processes occurring in a unique environment. Unlike western Pacific back-arc basins (Taylor and Natland, 1995), Bransfield basin is an actively extending former accretionary wedge (Storey and Garrett, 1985) without a currently active seafloor spreading center offshore. There are very few examples on Earth of a spreading center, in this case the former Phoenix-Antarctic spreading center, ceasing to spread and leaving the nearby subducted slab "frozen in place" (Lawver et al, 1995). Normally the spreading center is active until it is subducted and the slab is free to sink into the mantle. A possible analog to the Bransfield basin situation is the western United States where the subducted slab is anomalously shallow under the extending Basin and Range. Although the lower plate may be gradually sinking below Bransfield basin, it is not free to continue subduction into the mantle (Fig. 2). Therefore, any subduction now occurring at the South Shetland Trench may simply be the result of trench rollback caused by oceanward movement of the South Shetland Islands block. Where the former Phoenix-Antarctic spreading center was subducted immediately to the southwest of Hero fracture zone (Plate 1), the detached descending slab leaves a "slab window" behind (Hole et al., 1991; Hole and Larter, 1993). The only deep earthquakes reported below Bransfield basin (Pelayo and Wiens, 1989) are either related to the present-day volcanic activity, particularly below Deception Island and Bridgeman Island, or are possibly related to tearing along the subducted part of the Hero Fracture Zone (Plate 1, lower right) where the former Phoenix-Antarctic spreading center to the southwest was subducted and the remainder of the former Phoenix plate, now partially below the South Shetland Islands, remains unable to detach and slide into the mantle (Lawver et al., 1995).

Seabeam 2112 multibeam bathymetric charts illustrate episodes of northwest-southeast extension in Bransfield basin, with at least four or more nearly parallel cracks leaking vesicular basalt magma to the seafloor. We believe that there is no evidence in Bransfield basin for seafloor spreading as commonly defined in either a back-arc basin or a mid-ocean ridge sense. Extension is occurring, but the long, linear magmatic intrusions observed at the seafloor are probably filling extensional cracks produced by stretching the Paleozoic to Mesozoic accretionary wedge material. The 5 to 15 km estimate of extension of González-Ferrán (1991) is consistent with the amount of intrusive material observed from multichannel seismic reflection data. The volcanic extrusions produce a large positive anomaly, because the vesicular basalt is chilled at the surface and the present-day magnetic field signal is frozen into it. Even so, the 5 to 15 km of extension may have begun at the time of cessation of spreading on the Phoenix-Antarctic Ridge (4 Ma) or may have begun prior to that time. Since subsurface intrusions do not have an induced magnetic field (Lawver and Hawkins, 1978), it is futile at this time to attempt to suggest a spreading rate for Bransfield basin.

Evidence suggesting hydrothermal venting was found along three of the seafloor highs. It was not found in the submarine Orca Volcano, which leads us to think that Orca Volcano is older than it appears. No evidence for splitting of volcanic calderas by regional extension was observed, and it is most probable that Orca Volcano and the supposedly split Edifice A are in fact the last stage eruptive activities along their linear rift structures rather than initial ones. Extensional activity seems instead to be shifting to the southeast, as suggested by Barker and Austin (1994).

Opening of Bransfield basin is not produced by typical back-arc basin extension of the type that involves active spreading processes and subduction. No active arc exists, nor is there a subducted slab sliding into the mantle, opening a "slab-window" as was the case along the Antarctic Peninsula to the south (Hole and Larter, 1993) and to the north along the South American margin in southern Patagonia (Ramos and Kay, 1992). Instead, as shown in Figure 2C, the slab is pinned and the plate reorganization resulting from the cessation of spreading at the Phoenix-Antarctic spreading center may be producing stresses (Fig. 2B) that, combined with the effect of vertical slab sinking (Fig. 2C) result in slight trench rollback and a minor amount of extension, almost cracking, that allow linear magmatic intrusions to be emplaced into an extended continental margin.

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REFERENCES CITED

Acosta, J., Herranz, P., Sanz, J. L., and Uchupi, E., 1992, Antarctic continental margin: Geological image of the Bransfield Trough, an incipient oceanic basin, *in* Poag, C. W., and Graciansky, P. C., eds., Geological evolution of Atlantic continental rises: New York, Van Nostrand Reinhold, p. 49–61.

Barker, D. H. N., and Austin, J.A., Jr., 1994, Crustal diapirism in Bransfield Strait, West Antarctica—evidence for distributed extension in marginal basin formation: Geology, v. 22, p. 657–660.

Barker, D. H. N., and Austin, J. A., Jr., 1995, A microcosm of passive margin formation: Marginal basin rifting, Bransfield Strait, Antarctica, [abs.]: Eos (Transactions, American Geophysical Union), v. 76, p. F546.

Barker, P. F., 1976, The tectonic framework of Cenozoic volcanism in the Scotia Sea region, a review, *in* González-Ferrán, O., ed., Andean and Antarctic volcanology problems: Rome, International Association of Volcanology and Chemistry of the Earth's Interior, p. 330–346.

Barker, P. F., 1982, The Cenozoic subduction history of the Pacific margin of the Antarctic Peninsula: Ridge crest–trench interactions: Geological Society of London Journal, v. 139, p. 787–801.

Barker, P. F., and Dalziel, I. W. D., 1983, Progress in geodynamics of the Scotia Arc region, *in* Cabre, R., ed., Geodynamics of the eastern Pacific region, Caribbean and Scotia arcs: American Geophysical Union Geodynamics Series, v. 9, p. 137–170.

Barker, P. F., Dalziel, I. W. D., and Storey, B. C., 1991, Tectonic development of the Scotia Arc region, *in* Tingey, R. J., ed., The geology of Antarctica: Oxford, UK, Oxford University Press, p. 215–248.

Birkenmajer, K., Delitala, M. C., Narębski, W., Nicoletti, M., and Petrucciani, C., 1986, Geochronology of Tertiary island-arc volcanics and glacigenic deposits, King George Island, South Shetland Islands (West Antarctica): Polish Academy of Sciences, Earth Sciences, v. 34, p. 257–273.

British Antarctic Survey, 1985, Tectonic map of the Scotia Arc, sheet (miscellaneous) 3: Cambridge, UK, British Antarctic Survey, scale 1:3 000 000.

Cunningham, W. D., Dalziel, I. W. D., Lee, T-Y., and Lawver, L. A., 1995, Southernmost South America–Antarctic Peninsula relative plate motions since 84 Ma: Implications for the tectonic evolution of the Scotia Arc region: Journal of Geophysical Research, v. 100, p. 8257–8266.

Dalziel, I. W. D., 1984, Tectonic evolution of a forearc terrane, southern Scotia Ridge, Antarctica, Geological Society of America Special Paper 200, 32 p.

Gambôa, L. A. P., and Maldonado, P. R., 1990, Geophysical investigations in the Bransfield Strait and in the Bellingshausen Sea, Antarctica, *in* St. John, B., ed., Antarctica as an exploration frontier: Hydrocarbon potential, geology and hazards: American Association of Petroleum Geologists Studies in Geology #31, p. 127–141.

Ghidella, M., and Holik, J., 1995, Onboard gravity data processing, NBP9507 Cruise, *RVIB N.B. Palmer* Cruise Report for Cruise NBP9507: Austin, Texas, UTIG Technical Report.

González-Ferrán, O., 1991, The Bransfield rift and its active volcanism, *in* Thomson, M. R. A., et al., eds., Geological evolution of Antarctica: Cambridge, UK, Cambridge University Press, p. 505–509.

Gracia, E., Canals, M., Farran, M. L, Prieto, M. J., Sorribas, J., and GEBRA Team, 1996, Morphostructure and evolution of the Central and Eastern Bransfield basins (NW Antarctic Peninsula): Marine Geophysical Research, v. 18, p. 429–448.

Grad, M., Guterch, A., and Janik, T., 1993, Seismic structure of the lithosphere across the zone of subducted Drake plate under the Antarctic plate, West Antarctica: Geophysical Journal International, v. 115, p. 586–600.

GRAPE Team, 1990, Preliminary results of seismic reflection investigations and associated geophysical studies in the area of the Antarctic Peninsula: Antarctic Science, v. 2, p. 223–234.

Grunow, A. M., Dalziel, I. W. D., Harrison, T. M., and Heizler, M. T., 1992, Structural geology and geochronology of subduction complexes along the margin of Gondwanaland: New data from the Antarctic Peninsula and southernmost Andes: Geological Society of America Bulletin, v. 104, p. 1497–1514.

Guterch, A., Grad, M., Janik, T., and Perchuc, E., 1992, Tectonophysical models of the crust between the Antarctic Peninsula and the South Shetland trench, *in* Thomson, M. R. A., et al., eds., Geological evolution of Antarctica: Cambridge, UK, Cambridge University Press, p. 499–504.

Hawkins, J. W., 1995, Evolution of the Lau Basin—Insights from ODP Leg 135, *in* Taylor, B., and Natland, J., eds., Active margins and marginal basins of the western Pacific: American Geophysical Union Monograph 88, p. 125–174.

Hole, M. J., Rogers, G., Saunders, A.D., and Storey, M., 1991, Relation between alkalic volcanism and slab-window formation: Geology, v. 19, p. 657–660.

Hole, M. J., and Larter, R. D., 1993, Trench-proximal volcanism following ridge crest–trench collision along the Antarctic Peninsula: Tectonics, v. 12, p. 897–910.

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Presidential Conference Scheduled

Ethics in the Geosciences

A Geological Society of America Presidential Conference, "Ethics in the Geosciences," will be held July 16–21, 1997, at the Resort at the Mountain, Welches, Oregon, on the flanks of Mount Hood. Cosponsors are GSA and the American Association of Petroleum Geologists.

Purpose and Goals

Unethical conduct and practices are increasing within the geoscience and other scientific communities. Such unethical practices include, but are not limited to, falsification of data, deliberate misrepresentation of qualifications and/or professional registrations, plagiarism, and willful misrepresentation of scientific knowledge in research or to accommodate a client or legal position. This conference will address the complex issues of ethical behavior by providing a forum for input and discussion of ethics and the geosciences among professionals in the disciplines.

GSA Presidential Conferences operate under Penrose Conference guidelines. The presentation format includes keynote addresses, panel discussions, ad hoc working groups, and poster sessions. As an exception to the Penrose format, participants are allowed and encouraged to disseminate information after the conference.

The primary goals of the 1997 conference are (1) to promote a dialogue within the geosciences community on ethical issues—issues that are not currently a part of the geoscientist's typical education or professional experience; and (2) to develop a framework for assembly and dissemination of information on ethical issues within the geoscience community. Discussions will focus on:

- identification of the types of ethical systems;
- cultural controls on ethical behavior (conflict of ethical systems);
- case histories of ethics violations or perceived violations;
- professional certification, licensing, registration, and enforcement as applied to an ethical framework;
- legal protection associated with enforcement;
- existing codes of ethics from various professional societies and organizations;
- means of instilling and fostering ethical behavior.

This conference will assemble an interdisciplinary group of participants who will serve as catalysts within the geosciences community in the promotion of ethical behavior. The conference topic—"Ethics in the Geosciences"—is an issue that geoscientists need to address and debate in order to create an effective interface between geology and the public. (Indeed, a requirement for a Presidential Conference is that topics must focus on the interface between geology and the public.) Anticipated results of this conference are:

- establishment of increased and more productive communication between geoscientists and behavioral scientists;
- creation of a focus on ethical issues and concepts that can be readily disseminated to the geoscience community;
- identification of methods for fostering and promoting ethical practices;
- development of an agenda for follow-up and future action;
- preparation of guidelines for developing a uniform code of ethics for consideration and adoption by the geoscience community.

Conference Participants

The conference will be limited to 100 participants. Of this number, about 75% will be geoscientists, and the balance

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Bathymetry *continued from p. 5*

Keller, R. A., 1996, The petrology, geochemistry, and geochronology of hotspot seamounts in the north Pacific and arc/backarc volcanism on the northern Antarctic Peninsula [Ph.D. thesis]: Corvallis, Oregon State University.

Keller, R. A., Fisk, M. R., Smellie, J. L., Strelin, J. A., and Lawver, L. A., 1996, Geochemistry of backarc basin volcanism in Bransfield Strait, Antarctica: Subducted contributions and along-axis variations, *in* Keller, R. A., The petrology, geochemistry, and geochronology of hotspot seamounts in the north Pacific and arc/backarc volcanism on the northern Antarctic Peninsula [Ph.D. thesis]: Corvallis, Oregon State University, p. 72–100.

Klepeis, K. A., 1993, Structural studies of deformation along convergent and transform plate boundaries in the western Scotia Arc [Ph.D. thesis]: Austin, University of Texas, 232 p.

Klepeis, K. A., and Lawver, L. A., 1994, Bathymetry of the Bransfield Strait, southeastern Shackleton Fracture Zone and South Shetland Trench: Antarctic Journal of the United States, v. XXVII, p. 103–104.

Klepeis, K., and Lawver, L. A., 1996, Tectonics of the Antarctic-Scotia plate boundary near Elephant and Clarence islands, West Antarctica: Journal of Geophysical Research, v. 101, p. 20,211–20,231.

Klinkhammer, G. P., Chin, C. S., Wilson, C., Rudnicki, M. D., Keller, R. A., Fisk, M. R., and Lawver, L. A., 1995. Results of a search for hydrothermal activity in the Bransfield Strait, Antarctica: Eos (Transactions, American Geophysical Union), v. 76, p. F710.

Larter, R. D., and Barker, P. F., 1991, Effects of ridge crest–trench interaction on Antarctic-Phoenix spreading: Forces on a young subducting plate: Journal of Geophysical Research, v. 96, p. 19,583–19,607.

Lawver, L. A., and Hawkins, J. W., 1978, Diffuse magnetic anomalies in marginal basins: Their possible tectonic and petrologic significance: Tectonophysics, v. 45, p. 323–338.

Lawver, L. A., Gahagan, L. M., and Coffin, M. F., 1992, The development of paleoseaways around Antarctica, *in* Kennett, J. P., and Warnke, D. A., eds., The Antarctic paleoenvironment: A perspective on global change: American Geophysical Union Antarctic Research Series, v. 56, p. 7–30.

Lawver, L. A., Keller, R. A., Fisk, M. R., and Strelin, J. A., 1995, Bransfield Strait, Antarctic Peninsula: Active extension behind a dead arc, *in* Taylor, B., ed., Back arc basins: Tectonics and magmatism volume: Amsterdam, Plenum Press, p. 315–342.

Nagihara, S., and Lawver, L. A., 1989, Heat flow measurements in the King George Basin, Bransfield Strait: Antarctic Journal of Science, p. 123–125.

Pankhurst, R. J., 1983, Rb-Sr constraints on the ages of basement rocks of the Antarctic Peninsula, *in* Oliver, R. L., et al., eds., Antarctic earth science: Canberra, Australian Academy of Science, p. 367–371.

Pankhurst, R. J., and Smellie, J. L., 1983, K-Ar geochronology of the South Shetland Islands, Lesser Antarctica: Apparent lateral migration of Jurassic to Quaternary island arc volcanism: Earth and Planetary Science Letters, v. 66, p. 214–222.

Pelayo, A. M., and Wiens, D. A., 1989, Seismotectonics and relative plate motions in the Scotia Sea region: Journal of Geophysical Research, v. 94, p. 7293–7320.

Ramos, V. A., and Mahlburg Kay, S., 1992, Southern Patagonian plateau basalts and deformation: Backarc testimony of ridge collision: Tectonophysics, v. 205, p. 261–282.

Roach, P. J., 1978, The nature of back-arc extension in Bransfield Strait [abs.]: Royal Astronomical Society Geophysical Journal, v. 53, p. 165.

Sandwell, D. T., and Smith, W. H. F., 1992, Global marine gravity from ERS-1 Geosat and Seosat reveals new tectonic fabric: Eos (Transactions, American Geophysical Union), v. 73, p. 133.

Smellie, J. L., 1990, Graham Land and South Shetland Islands, *in* LeMasurier, W. E., and Thomson, J. W., eds., Volcanoes of the Antarctic plate and southern oceans: Antarctic Research Series, v. 48, American Geophysical Union, p. 302–359.

Storey, B. C., and Garrett, S. W., 1985, Crustal growth in the Antarctic Peninsula by accretion, magmatism and extension: Geological Magazine, v. 122, p. 5–14.

Tanner, P. W. G., Pankhurst, R. J., and Hyden, G., 1982, Radiometric evidence for the age of the subduction complex of the South Orkney and South Shetland Islands, West Antarctica: Geological Society of London Journal, v. 139, p. 683–690.

Taylor, B., and, Natland, J., editors, 1995, Active margins and marginal basins of the western Pacific: American Geophysical Union Monograph 88, 417 p.

Wessel, P., and Smith, W. H. F., 1995, A new version of the Generic Mapping Tools (GMT): Eos (Transactions, American Geophysical Union), v. 76, p. 329.

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